Jet Propulsion Laboratory
California Institute of Technology

Response to Gateway Technology Utilization RFI

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Mission Design and Navigation Section

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SUMMARY

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The DPS-Navigator extends the concept of the Global Positioning System to cislunar space and throughout the solar system. DPS-Navigator provides a no-worry “bolt-on” onboard solution to the problem of ”where am I?” and further answers the question “How do I maintain my orbit?”

NASA JPL has a successful history of integrating sensors and flight software to accomplish complex onboard mission functions (e.g., EDL, formation flying, science operations, etc.). The proposed DPS-Navigator leverages prior demonstrations of autonomous navigation (DS-1, Deep Impact, Stardust) to provide a more general and robust onboard solution to maintain the Gateway orbit when the crew is not present or to reduce the crew's dependence on ground-based mission control. When not needed for autonomous navigation, the DPS-Navigator could be used for other purposes including monitoring nearby vehicles or capturing science images.

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A: INTRODUCTION

- NASA JPL presents the following information in response to the Gateway Technology Utilization Request for Information (RFI), dated May 10, 2018.
- This response is intended to assist in the planning and development for utilizing the Gateway as a test bed for new technologies, and to identify opportunities for public-private partnerships beginning with the Exploration Mission-2 (EM-2).
- NASA JPL proposes the DPS-Navigator in response to several high priority areas listed in the RFI.
- If you have questions or require more information, please contact:

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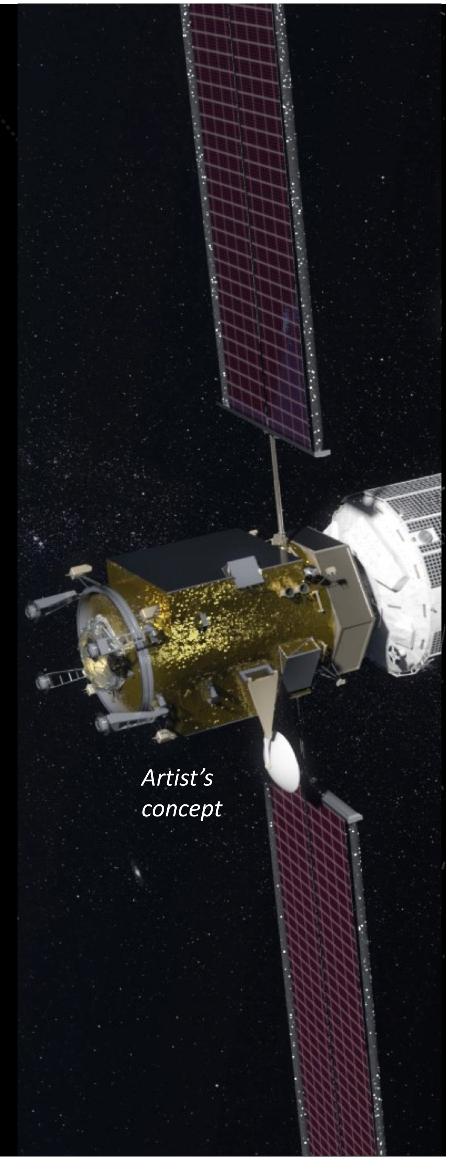

Artist's concept

Predecisional information, for planning and discussion only

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B: TECHNOLOGY DEMONSTRATION CONCEPT (1/6)

- B1: The Deep Space Positioning System (DPS)-Navigator concept is a self-contained autonomous navigation hardware and software system that provides spacecraft onboard navigation throughout the solar system.

- B1: It works like the Global Positioning System (GPS), but without the need for the satellite infrastructure. For LOP-Gateway, DPS-Navigator observes lunar landmarks to determine position information and computes orbital maneuvers to maintain the Gateway orbit when the crew is not present or to reduce the crew's dependence on ground-based mission control.

- B1: DPS-Navigator leverages NASA SMD developed camera technology. The DPS-Navigator provides precise lunar landmark measurements using narrow angle Field of View (FOV) optics and precise pointing knowledge using wide angle FOV optics. Onboard navigation performance with lunar landmarks is sufficiently accurate to provide an alternative to traditional Earth-based radiometric techniques; thus, freeing Earth tracking stations and ground personnel for other support.

Optical landmark tracking is capable of determining LOP-Gateway orbits to better than 100 m and 10 cm/s.

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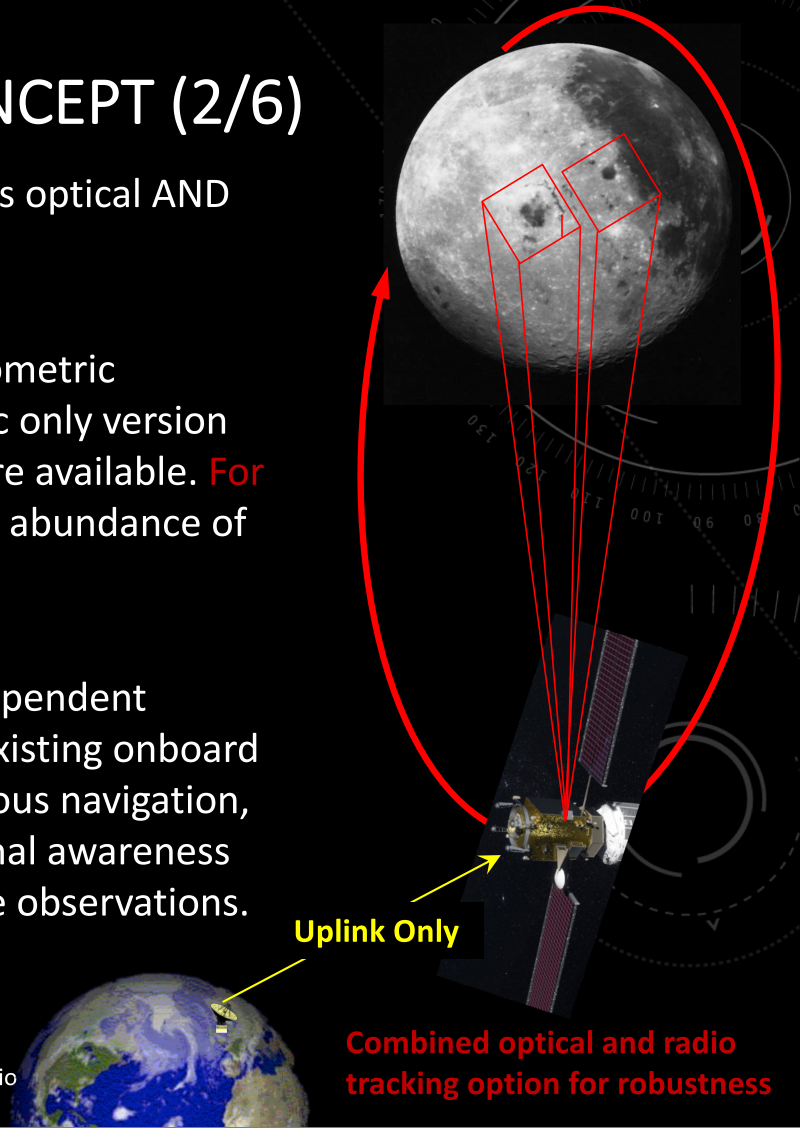
B: TECHNOLOGY DEMONSTRATION CONCEPT (2/6)

- B1: The most robust configuration of the DPS-Navigator uses optical AND radiometric sensing.

- B1: For applications beyond the moon, the addition of radiometric measurements adds robustness. Alternatively, a radiometric only version of DPS-Navigator could be used when few optical sources are available. For LOP-Gateway, the optical only version is proposed given the abundance of optical targets in the form of lunar surface landmarks.

- B1: Minimally, DPS-Navigator can be a source for Earth-independent navigation measurements (optical sensor data) for use by existing onboard GN&C systems (e.g. Orion). When not needed for autonomous navigation, the DPS-Navigator wide angle optics could support situational awareness or the narrow angle camera could be used to collect science observations.



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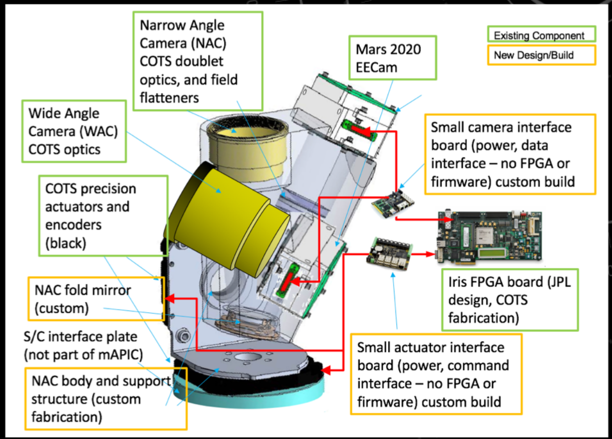
B: TECHNOLOGY DEMONSTRATION CONCEPT (3/6)

B2: The optical only version of DPS-Navigator integrates several flight-proven or flight-inherited technologies – Overall TRL 5:

- Camera: NASA SMD developed Mini Advanced Pointing Imaging Camera, TRL 6 by end of FY19.
  - Electronics & Detectors: Mars2020 EECam CMOS 20 Megapixel - TRL 7 now, TRL 8 by end of FY19.
  - Gimbals: Motor-actuators and rate control – commercial equipment, with flight heritage: TRL 7-8
- Sphinx Central Processing Unit: NEA Scout, Lunar Flashlight to be launched with EM-1, TRL 7
- Flight S/W: Deep Impact “AutoNav” autonomous navigation flight software, updated and upgraded with JPL internally funded R&D and ongoing SBIR Phase 2 project, TRL 6



Concept Drawing of Mini Advanced Pointing Imaging Camera

Is a high-resolution imaging system that simultaneously takes images of targets and star fields with two-axis gimbal control capability, allowing rapid target imaging and image motion compensation with extremely precise pointing knowledge.

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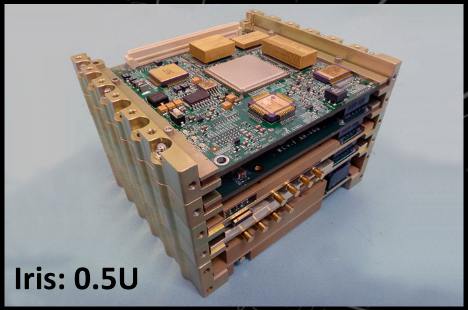
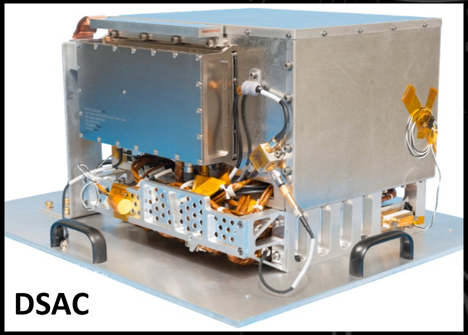
B: TECHNOLOGY DEMONSTRATION CONCEPT (4/6)

B2: Adding radiometric measurements to DPS-Navigator integrates the following flight heritage technologies - Overall TRL 5:

- Software Defined Radio (SDR): Iris (currently flying on MarCO cubesats to Mars), TRL 8
  - Onboard navigation functions can be hosted in SDR CPU potentially removing need for Sphinx CPU
- Reflectarray X-band antenna: MarCO, TRL 8
- Atomic Clock: Compact Deep Space Atomic Clock (DSAC), TRL 6





An Iris SDR (top) and a compact version of the Deep Space Atomic Clock (bottom) would be used for autonomous 1-way radio navigation.

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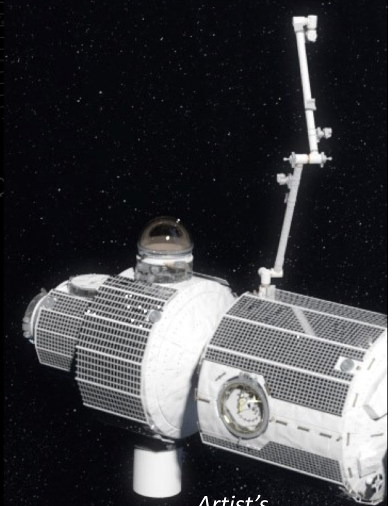
B: TECHNOLOGY DEMONSTRATION CONCEPT (5/6)

- B3: The optical only design is small (25 x 12 x 12 cm) and light weight, < 5 kg. Power requirements are <12 W with self-contained processing. Data link requirements (periodically for set-up, monitoring, and maintenance) of < 50 Mb per day.

- B4: Operational Requirements:
  - 2-DOF gimbal mount location needed for views of lunar landmarks
  - Interfaces:
    - Propulsion (to Gateway): maneuver design (Delta-V vector, epoch and duration)
    - Propulsion (from DPS-Navigator): actual execution time and thruster on-times
    - Power
    - Ground/Flight command and telemetry



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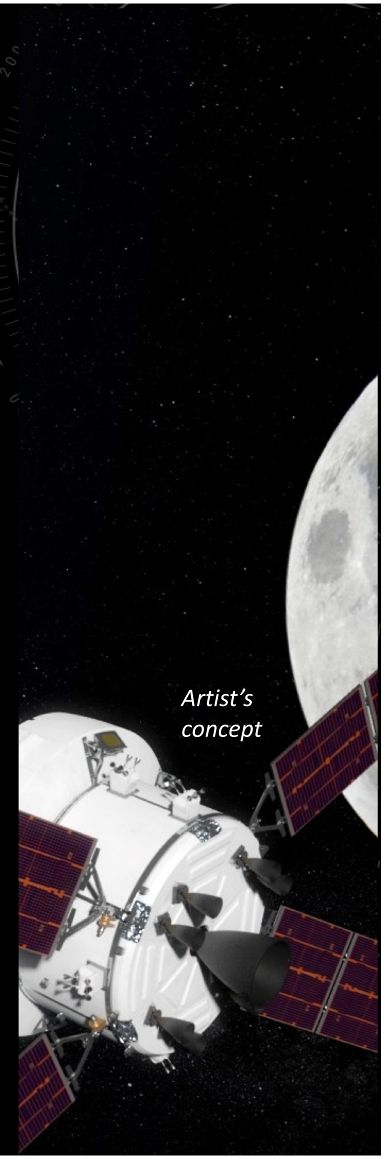
B: TECHNOLOGY DEMONSTRATION CONCEPT (6/6)

- B5: Development opportunities through public-private partnerships:
    - Blue Sun Enterprises (Boulder, CO) is a potential partner to provide real-time command and control software
    - Advanced Solutions Inc. (Littleton, CO) is a potential partner for instrument, processor, and h/w and s/w integration
    - Eidetic Optical Systems (Valencia, CA) is a potential partner for building and testing the optical instrument – and is currently building the mini-APIC engineering prototype
    - Space Dynamics Laboratory (Utah State University) fabrication and testing of the Iris radio in NASA-certified facilities
    - MicroChip and/or Frequency Electronics Inc. are potential partners for a commercialized, reduced SWaP compact DSAC
    - Commercial visiting vehicle providers (SpaceX, Boeing, Sierra Nevada, Blue Origin, etc.)



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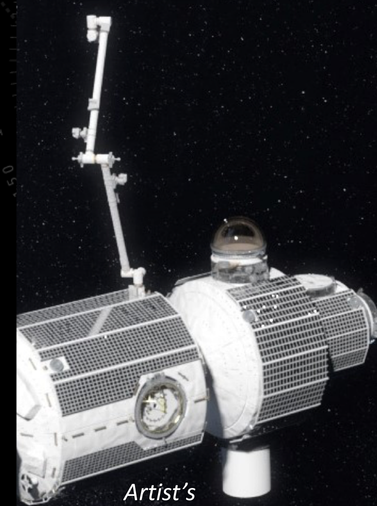
C: RELEVANCE TO RFI OBJECTIVES (1/2)

C1: Demonstration of the DPS-Navigator in cislunar space is required to confirm functionality in the severe radiation environment unprotected by Earth's magnetosphere. DPS-Navigator sensors have completed Earth-based verification and the next step is to be proven in cislunar deep space.

C2: Use of DPS-Navigator provides orbit determination and control functions that could lead to a completely self-maintaining vehicle. It also allows for general automation of other onboard features such as collision avoidance using the inherent positioning capabilities. Once demonstrated, DPS-Navigator can be utilized immediately at LOP-Gateway.

C3: Like GPS receivers in low Earth orbit and star trackers, the use of DPS-Navigator will free the crew and ground support from mundane and repetitive responsibilities of Navigation tasks, and prepare for missions beyond the lunar environment (e.g., Mars and small bodies)



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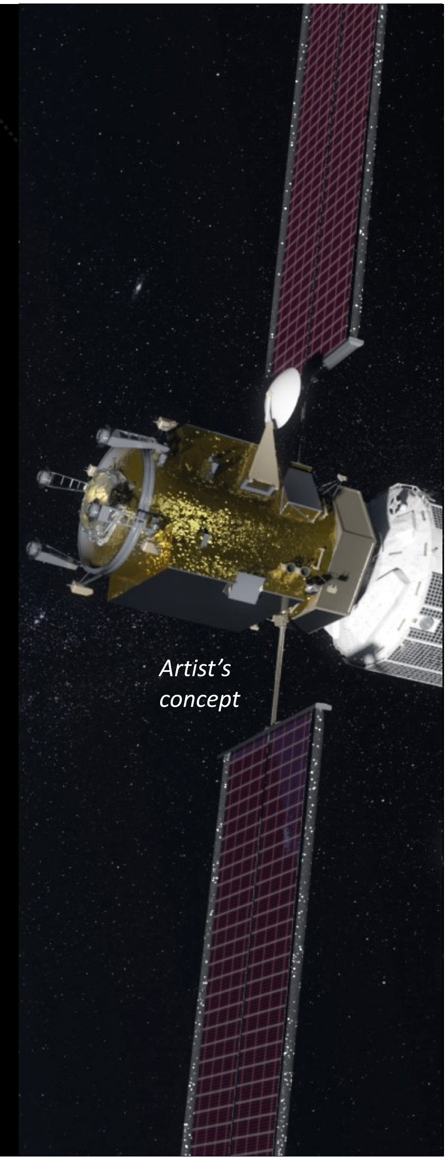
C: RELEVANCE TO RFI OBJECTIVES (2/2)

C4: Spacecraft navigation without GPS is required for all deep space missions. Applying DPS-Navigator to future government or commercial vehicles would provide navigation consistency and enhance interoperability between robotic and crewed missions.

C5: The proposed private-public partnerships builds on over ten years of R&D and SBIR technology developments in autonomy and autonomous navigation. GPS-Navigator builds on substantial NASA SMD investments in high-performance instrument miniaturization (mini APIC), NASA HEOMD investments (Iris), and NASA STMD investments in precision onboard timing (DSAC).

C5: There is considerable potential for use of DPS-Navigator on various elements of LOP-Gateway as well as future missions beyond cislunar space. DPS-Navigator's small size, power and weight lends itself to a variety of missions from smallsats to flagships. Once DPS-Navigator is demonstrated, infusion for use on LOP-Gateway or future Deep Space Transports could be immediate.



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